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BALANÇO DE ÁGUA EM SOLOS COESOS DE TABULEIROS COSTEIROS SOB EUCALIPTO, PASTAGEM E MATA NATIVA

EMANUELA BARBOSA SANTOS[1]; LUCIANO DA SILVA SOUZA[2]; FELIPE GOMES FREDERICO DA SILVEIRA[3]; ELTON DA SILVA LEITE[4] E EVELLYN FREIRE DA SILVA[5]

[1]Engenheira Agrônoma e Doutoranda em Ciência do Solo, Departamento de Ciências do Solo, Universidade Federal do Ceará, Avenida Mister Hull, 2977, Pici, 60356-000, Fortaleza, Ceará, Brasil. E-mail: emanuelabarbbosa@gmail.com
[2]Engenheiro Agrônomo, Doutor em Ciência do Solo, Professor Adjunto do Centro de Ciências Agrárias, Ambientais e Biológicas da Universidade Federal do Recôncavo da Bahia, Rua Rui Barbosa, 710, Centro,44.380-000, Cruz das Almas, Bahia, Brasil. E-mail: lsouza@ufrb.edu.br
[3]Engenheiro Agrônomo, Doutor em Produção Vegetal, Professor do Polo de Engenharia da Faculdade de Ciências e Empreendedorismo, Praça Dr. Renato Machado, 10, Centro, 44430-158, Santo Antônio de Jesus, Bahia, Brasil. E-mail: felipe.silveira@facemp.edu.br
[4]Engenheiro Florestal, Doutor em Engenharia Agrícola, Professor Associado do Centro de Ciências Agrárias, Ambientais e Biológicas da Universidade Federal do Recôncavo da Bahia, Rua Rui Barbosa, 710, Centro,44.380-000, Cruz das Almas, Bahia, Brasil. E-mail: elton@ufrb.edu.br
[5]Engenheira Agrônoma e Doutoranda em Engenharia de Sistemas Agrícolas, Departamento de Engenharia de Biossistemas, Escola Superior de Agricultura Luiz de Queiroz/USP, Avenida Pádua Dias, 11, São Dimas, 13418-900, Piracicaba, São Paulo, Brasil. E-mail: evellynagro@gmail.com

1 RESUMO

A complexidade físico-climática dos Tabuleiros Costeiros exige conhecimento sobre o regime hídrico do solo e a disponibilidade de água para as plantas de maneira crucial para o desenvolvimento sustentável nessa região do Nordeste Brasileiro. Com isso, objetivou-se com esse trabalho avaliar o regime hídrico de solos com horizonte de caráter coeso de Tabuleiros Costeiros sob eucalipto, pastagem e mata nativa, por meio do estudo do balanço de água no solo. Os solos sob mata nativa e pastagem foram classificados como ARGISSOLO AMARELO e sob eucalipto como LATOSSOLO AMARELO. As medidas foram realizadas no Município de Cruz das Almas, Bahia, durante dez meses, incluindo períodos chuvosos e secos. Foram instaladas seis sondas de TDR no solo nas profundidades de 0,10 a 1,10 m, em cada área, com medições semanais. Encontrou-se nas áreas ocupadas por pastagem e eucalipto uma maior demanda evapotranspirativa em comparação com a mata nativa, indicando que a conversão do uso da terra tem impacto direto no balanço hídrico. A evapotranspiração (ET) seguiu as variações da precipitação pluvial, sendo que a redução da ET coincidiu com o período de maior déficit hídrico no solo entre as épocas avaliadas.

Palavras-chave: armazenagem de água, dinâmica de água, evapotranspiração.

SANTOS, E.B; SOUZA, L. S; SILVEIRA, F. G. F; LEITE, E. S; SILVA, E.F.

WATER BALANCE IN COHESIVE SOILS OF COASTAL TABLE LANDS UNDER EUCALYPTUS, PASTURE AND NATIVE FOREST

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2 ABSTRACT

The physical-climatic complexity of the Coastal Table Lands requires knowledge about the soil water regime and the availability of water for plants, crucially for sustainable development in this region of Northeastern Brazil. The objective of this work was to evaluate the water regime of cohesive soils of this ecosystem under eucalyptus, pasture and native forest, through the study of soil water balance. Soils under native forest and pasture were classified as Oxisol and under eucalyptus as Ultisol. The measures were carried out in the Municipality of Cruz das Almas, Bahia, Brazil, in ten months, including rainy and dry periods. Six TDR probes were installed in the soil at depths of 0.10 to 1.10 m, in each area, with weekly measurements. It was concluded that the soil water balance showed that pasture and eucalyptus showed higher evapotranspirative demand compared to native forest, allowing to infer that more attention is needed in relation to water resources in areas where those crops are present. The evapotranspiration (ET) followed the rainfall variations, and the ET reduction coincided with the greatest water deficit in the soil between the evaluated periods.

Keywords: evapotranspiration, water dynamics, water storage.

3 INTRODUCTION

In Brazil, coastal Tablelands represent an area that stretches from the Amazon Region to Rio de Janeiro and has an estimated area of 20 million hectares, with the Northeast Region occupying an area of approximately 10 million hectares (SOUZA, 2008). The main soil classes found in the coastal lands are yellow argisols and yellow latosols (CORRÊA *et al*., 2008), both of which present physical and chemical attributes that restrict use and management.

The presence of a cohesive layer is common in the soils of coastal Tablelands; therefore, these soils present difficulties in water movement and storage, which prevents plant roots from deepening. Furthermore, the drought that hit Northeast China in early 2012, which has continued this day, was the worst in the last 30 years, and the state of Bahia, especially the northern portion, was the most affected by the lack of rainfall. Droughts are part of the natural variability of the coastal Tablelands climate. They have occurred in the past, are now occurring, and, according to climate change projections, are likely to continue and intensify in the future (MARENGO; CUNHA; ALVES, 2016). A thorough understanding of the soil water regime and water availability for plants in this region is crucial for implementing agricultural and environmental management strategies aimed at maximizing water resources and soil conservation (CINTRA *et al*., 2009).

The water dynamics of an ecosystem can be studied on the basis of the soil water balance, which is obtained from data on water storage variations in the soil profile, rainfall, water volume applied via irrigation systems, drainage, capillary rise, and evapotranspiration (SILVA; COELHO; COELHO FILHO, 2015). According to Consoli *et al*. (2015), more accurate estimates of plant evapotranspiration rates and soil water dynamics and/or movement could be useful strategies for improving water use management.

In this sense, the time domain reflectometry (TDR) technique is one of the most accurate methods for measuring soil water and is based on the effect of soil moisture on the propagation speed of electromagnetic waves in sensor rods inserted in a porous medium (UMENYIORA *et al*., 2012). Naranjo and

Ataroff (2015) highlight this technique in relation to others because it is a fast, nondestructive method and makes automation possible for data acquisition, allowing continuity and automation in data collection, in a large number of repetitions over a long period of time.

The hypothesis of this study is that if the cohesive horizons present in coastal Tableland soils restrict vertical water flow in the profile, reducing water storage at depth over time, then periods of water deficit may occur for eucalyptus, pasture, and native forest throughout the year. This can be detected through the soil water balance over time and even allows for the discrimination of these three vegetation types in terms of water consumption.

In view of the above, the objective of this work was to evaluate the water regime of soils with a cohesive horizon of coastal listlands under eucalyptus, pasture and native forest crops through the study of the soil water balance.

4 MATERIALS AND METHODS

4.1 Description of the experimental locations

The water balance measurements were carried out in three different environments in the municipality of Cruz das Almas, Bahia state: in a pasture area with *Brachiaria decumbens* covering the entire soil surface, where the Meteorological Station of the Federal University of Recôncavo da Bahia (UFRB) is located; in an area cultivated with the eucalyptus hybrid *Eucalyptus grandis* x *E. urophylla*, which is also located in the UFRB; and in the Mata de Cazuzinha Forest Park, which is in a subevergreen forest. The eucalyptus area was divided into two treatments: an area with deep subsoiling and 0.57 manother without subsoiling, with planting in holes 0.30 m0.40 m deep and 0.40 m in diameter. Transplanting was carried out in September 2013 (MELO *et al*., 2018), and the present study was conducted between July 2016 and May 2017.

In each experimental area, profiles were opened next to the points under evaluation for morphological description and classification of the soils, in addition to collecting samples per horizon for physical characterization.

4.2 Physical analysis of soils

The granulometric analysis was performed via the pipette method (GEE; OR, 2002). The soils under pasture and native forest were classified as YELLOW ARGISSOIL Distrocohesive [Ferralic Xanthic Ferralsol (Densic); Oxisol], and those under eucalyptus were classified as Distrocohesive Yellow Latossol [(Ferralic Xanthic Acrisol (Densic); Ultisol)] (SANTOS *et al*., 2018; SOIL TAXONOMY, 2003).

The results of the granulometric analyses and the respective textural classes are presented in Table 1.

Table 1. Granulometric analysis of soils cultivated under pasture, eucalyptus and native forest, evaluated in Cruz das Almas, Bahia

Horizons	Prof.	Total sand	Silt	Clay	Textural class
	----- m -----	----------------- g kg $^{-1}$	---------------		
Distrocohesive Yellow Argisol (Pasture)					
THE	0-0.13	880	20	100	Loamy sand
AB	0.13-0.26	800	60	140	Sandy loam
BA	0.26-0.60	740	80	180	Sandy loam
Bt_1	0.60-1.21	620	55	325	Sandy clay loam
Bt_2	1.21-1.40 $^+$	535	55	410	Sandy clay
YELLOW LATOSOL Distrocohesive (Eucalyptus with and without subsoiling)					
THE	0-0.13	720	80	200	Sandy clay loam
AB	0.13-0.42	650	55	295	Sandy clay loam
BA	0.42-0.84	580	75	345	Sandy clay loam
Bw_1	0.84-1.12	480	85	435	Sandy clay
Bw_2	1.12-2.03 $^+$	440	40	520	Sandy clay
YELLOW ARGISSOIL Distrocohesive (Native forest)					
A_1	0-0.07	725	60	215	Sandy clay loam
AB_1	0.07-0.21	750	60	240	Sandy clay loam
AB_2	0.21-0.38	640	60	300	Sandy clay loam
BA	0.38-0.56	560	60	380	Sandy clay
Bt_1	0.56-0.85	550	70	380	Sandy clay
Bt_2	0.85-1.30 $^+$	420	50	530	Clayey

The particle density (D_p) was obtained via the volumetric flask method (50 mL), and the soil density (D_s) was obtained via the volumetric cylinder method (GROSSMAN; REINSCH, 2002). The total porosity (TP) was obtained from the values of D_p and D_s and the microporosity via the tension table method (OLIVEIRA, 1968), which is represented by the volumetric moisture in the sample after being subjected to a tension of 6 kPa. The macroporosity ($m^3\ m^{-3}$) was obtained from the difference between the PT and the microporosity. These last attributes are presented in Table 2.

Table 2. Physical attributes of soils cultivated under pasture, eucalyptus and native forest, evaluated in Cruz das Almas, Bahia

Horizons	**Prof.**	**PT [1]**	**Bad**	**Mi**	**Ds**	**Dp**
	---- m ----	--------------- $m^3 m^{-3}$		---------------	----- $kg\ dm^{-3}$	-----
Distrocohesive Yellow Argisol (Pasture)						
THE	0-0.13	0.3643	0.2243	0.1400	1.69	2.66
AB	0.13-0.26	0.4219	0.2836	0.1383	1.54	2.66
BA	0.26-0.60	0.4157	0.2533	0.1625	1.55	2.66
Bt_1	0.60-1.21	0.3798	0.1615	0.2183	1.54	2.48
Bt_2	1.21-1.40 +	0.4144	0.1582	0.2562	1.46	2.50
YELLOW LATOSOL Distrocohesive (Eucalyptus with and without subsoiling)						
THE	0-0.13	0.3407	0.1206	0.2201	1.63	2.47
AB	0.13-0.42	0.3802	0.1738	0.2065	1.55	2.51
BA	0.42-0.84	0.3875	0.1320	0.2555	1.52	2.47
Bw_1	0.84-1.12	0.4348	0.1517	0.2831	1.43	2.54
Bw_2	1.12-2.03 +	0.4317	0.1289	0.3029	1.39	2.44
YELLOW ARGISSOIL Distrocohesive (Native forest)						
A_1	0-0.07	... [2]	...	...	...	...
AB_1	0.07-0.21	0.4701	0.0948	0.3753	1.25	2.36
AB_2	0.21-0.38	0.4427	0.2325	0.2102	1.42	2.54
BA	0.38-0.56	0.4689	0.2509	0.2179	1.36	2.57
Bt_1	0.56-0.85	0.3839	0.2067	0.1771	1.47	2.38
Bt_2	0.85-1.30 +	0.4005	0.2585	0.1419	1.48	2.47

[1] PT = total porosity; Mp = macropores; mp = micropores; Ds = soil density; Dp = particle density.
[2] It was not possible to sample horizon A_1 because its thickness was very close to the height of the sampling cylinder.

The soil–water characteristic curves were prepared for each horizon via samples with preserved structures collected in volumetric cylinders with a capacity of 100 cm³ for tensions of 10, 33, 100, 300 and 500 kPa; for a tension of 1,500 kPa, air-dried fine Earth (ATFE) contained in a rubber ring was used. The equipment used in the determination was the Richards chamber (RICHARDS, 1949).

At the end of the application of tension, the samples were dried in an oven at 105 °C until a constant weight was obtained for determination of the gravimetric humidity ($kg\ kg^{-1}$), which was then transformed into volumetric humidity ($m^3 m^{-3}$) by multiplying by D_s.

From the moisture values associated with the stresses applied in the Richards chamber, the empirical parameters of the equation proposed by van Genuchten (1980) (Eq. 1) were obtained. The curves were adjusted via the Soil Water Retention Curves (SWRC) application (DOURADO NETO *et al*., 1990).

$$\theta = \theta_r + \frac{\theta_s - \theta_r}{[1+(\alpha|\varphi_m|)^n]^m} \qquad (1)$$

where θ is the volumetric moisture in $m^3 m^{-3}$; θ_r is the residual moisture in $m^3 m^{-3}$; θ_s is the saturation moisture in $m^3 m^{-3}$; ϕ_m is the matric potential in kPa; and α and men are the empirical coefficients of the equation.

were calibrated by collecting soil samples with an undisturbed structure. After this adjustment, the volumetric moisture data obtained by the probes installed in the experimental areas were converted to the matric potential, as explained in Equation (1). The total potential (sum of the matric and gravitational potentials) and the total soil water potential gradient at each depth were subsequently calculated via the Darcy–Buckingham equation (LIBARDI, 2018) (Eq. 2), which governs water flow in unsaturated soil:

$$q = -K(\theta)\frac{\varphi_{t(A)} - \varphi_{t(B)}}{L} \quad (2)$$

where q is the soil water flux density in ms $^{-1}$; $K(\theta)$ is the hydraulic conductivity as a function of the water content measured by the moisture sensors in ms $^{-1}$; ϕ_t is the total soil water potential at points A and B in m; and L is the distance between the two points in m.

The calculation of the total water potential gradient in the soil aimed to verify whether there was drainage (positive values) or capillary rise (negative values) at the lower limit of the evaluated soil volume.

4.3 Experimental setup and soil water balance determination

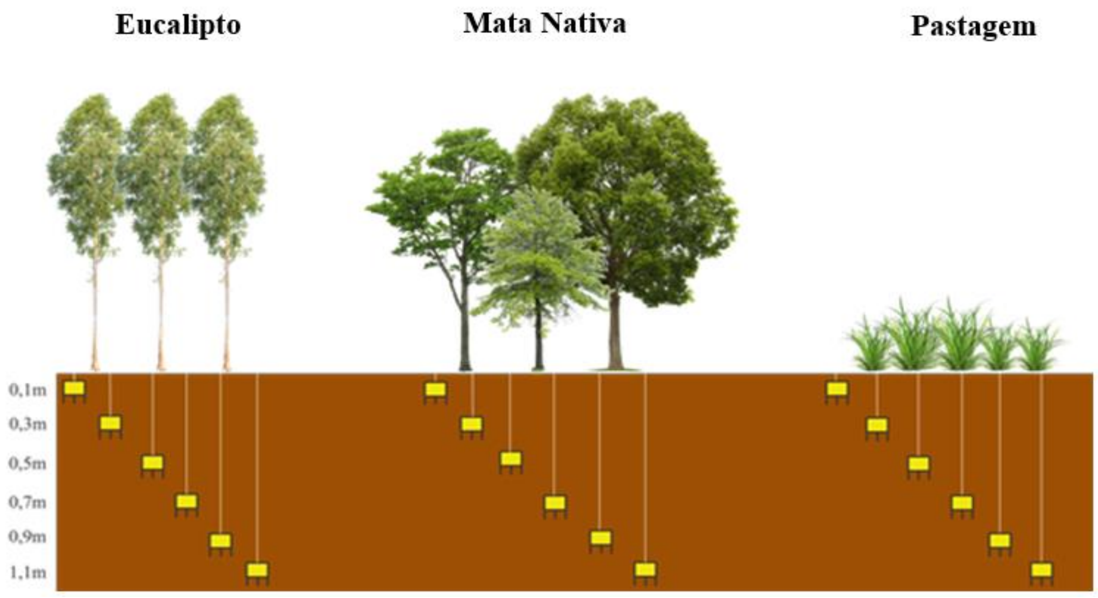
The TDR probes were introduced into the soil at six depths (0.10, 0.30, 0.50, 0.70, 0.90 and 1,10 m), with three replicates, totaling 18 probes in the vertical direction in each environment (Figure 1). In the area with eucalyptus, two types of management occurred, without subsoiling (SS) and with subsoiling (CS), totaling 72 experimental units.

The TDR equipment was programmed to take readings to estimate the soil water content via the equation of Ledieu *et al*. (1986) (Eq. 3):

$$\theta = 0{,}1138\sqrt{Ka} - 0{,}1758 \quad (3)$$

where θ is the soil water content, m ^{3} m $^{-3}$, and Ka is the soil dielectric constant, which is dimensionless.

Figure 1. TDR probes were installed at six depths (0.1, 0.3, 0.5, 0.7, 0.9 and 1.1 m) in each environment studied (eucalyptus, native forest and pasture).



Source: Authors.

Were taken over a 10-month period via a Campbell Scientific TDR 100. These readings were taken weekly, except when it rained between readings, when an additional reading was taken the day after the rain. Soil water storage was determined via the moisture values obtained from weekly TDR readings at depths of 0.0–1.10 m or the soil control volume.

Precipitation data were obtained through the meteorological station belonging to the institution for the eucalyptus and pasture environments and for the native forest environment, which was external to the institution. A rain gauge was installed on a tree close to the probes in which the precipitation value was measured.

The water balance was estimated on the basis of the principle of conservation of mass, which can be represented by the mathematical relationship between water inputs and outputs in a given volume of soil and can be described by the following equation (Eq. (4)):

$$\Delta \mathrm{ARM} = \mathrm{P} \pm \mathrm{D} - \mathrm{ET} \qquad (4)$$

where ΔARM is the variation in water storage in the soil profile during the period considered, in mm; P is the rainfall, in mm; D is the flux density, which may be internal drainage or capillary rise, in mm; and ET is the evapotranspiration, in mm.

The parameters I (irrigation) and R (surface and subsurface runoff), which are normally part of the soil water balance equation, were not considered in this work because the experiment was carried out under rainfed conditions and on soil with practically flat relief, where runoff was considered null.

The parameter D was not measured because of the lack of the K(θ) function (hydraulic conductivity × soil moisture), which could not be obtained by the instantaneous profile method in the three areas for practical reasons. However, the total soil water potential gradients, which are part of the Darcy–Buckingham equation (Eq. 2), were estimated to estimate the water flux density at the lower limit of the soil control volume, which corresponded to depths of 1,10 m.

Thus, with the moisture data in the soil profile and rainfall, the calculation of evapotranspiration was performed by explicitly expressing the term in the previous equation (Eq. 5):

$$\mathrm{ET} = \mathrm{P} - \Delta \mathrm{ARM} \qquad (5)$$

The soil water balance was calculated in four periods, which lasted 98, 96, 62, and 75 days. This subdivision aimed to characterize the rainiest periods (first and fourth periods) and the driest periods (second and third periods). The water balance components were calculated every eight days and integrated across the four periods evaluated.

4.5 Experimental design

The experimental design was completely randomized with split plots. Evapotranspiration data were subjected to analysis of variance, considering the environments as plots and the periods as subplots. The significant interaction between environments and periods was analyzed, and the Tukey test ($p < 0.05$) was used to compare the evapotranspiration means. Statistical analysis was performed via SAS 9.0 software (SAS Institute, 2004).

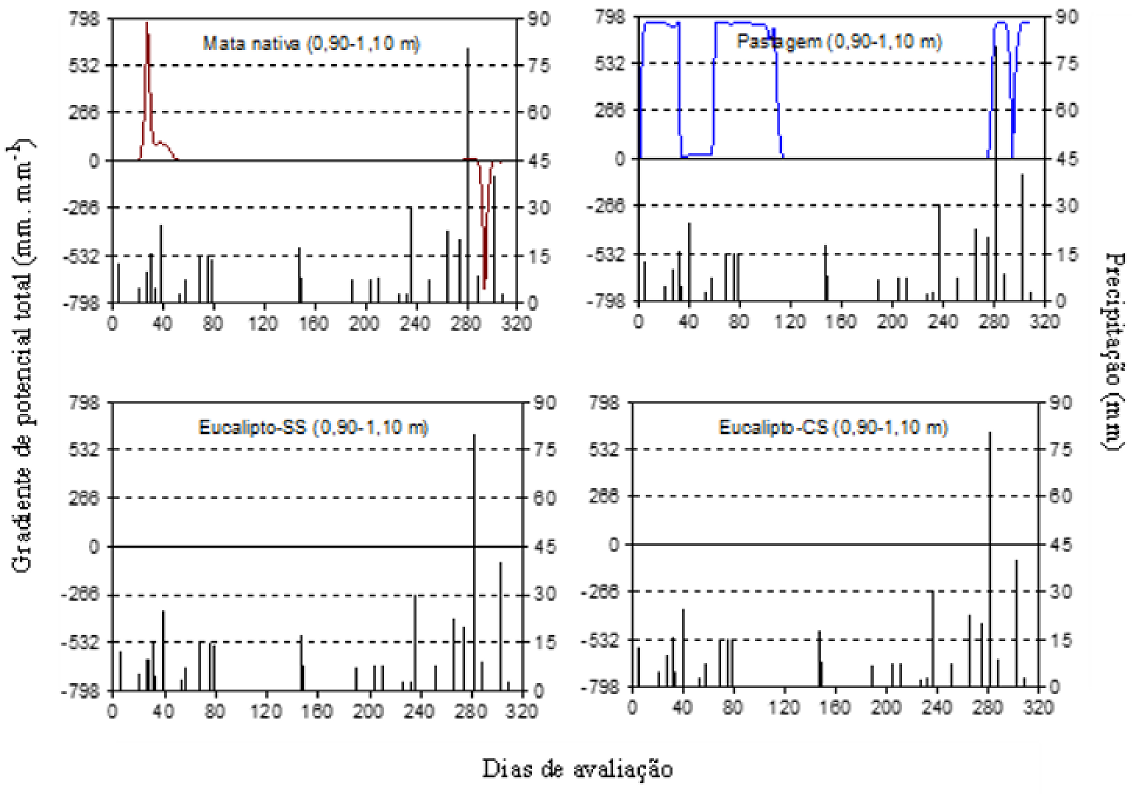
5 RESULTS AND DISCUSSION

Positive values of the total potential gradient indicate drainage, and negative values indicate capillary rise. The total potential gradients between the depths of 0.90–1.00/1.00–1,10 m, therefore, at the lower limit of the evaluated soil volume, were close to zero for most of the evaluation period (Figure 2).

Furthermore, the matric potential at the lower limit of the soil volume presented values close to or equal to -1500 kPa for most of the evaluation period (Figure 3). It is plausible that the hydraulic conductivity at that location was extremely low, allowing for the assumption of low or zero flow densities, whether by drainage or capillary rise, even during the rainiest periods. Therefore, it was justified to consider these components irrelevant in the water balance calculation.

Silveira *et al*. (2014), who studied water redistribution and the drying process in different horizons of a coastal plateau, Dystrocohesive Yellow Latosol, reported that the reduction in matric potential over time was slower in the AB and BA horizons, generally those that presented pedogenic consolidation in the evaluated soil. These horizons are just above the horizon that we defined as the lower limit in the present study (Table 2).

Figure 2. Total potential gradient at the lower soil limits during the environmental assessment period in Cruz das Almas, Bahia

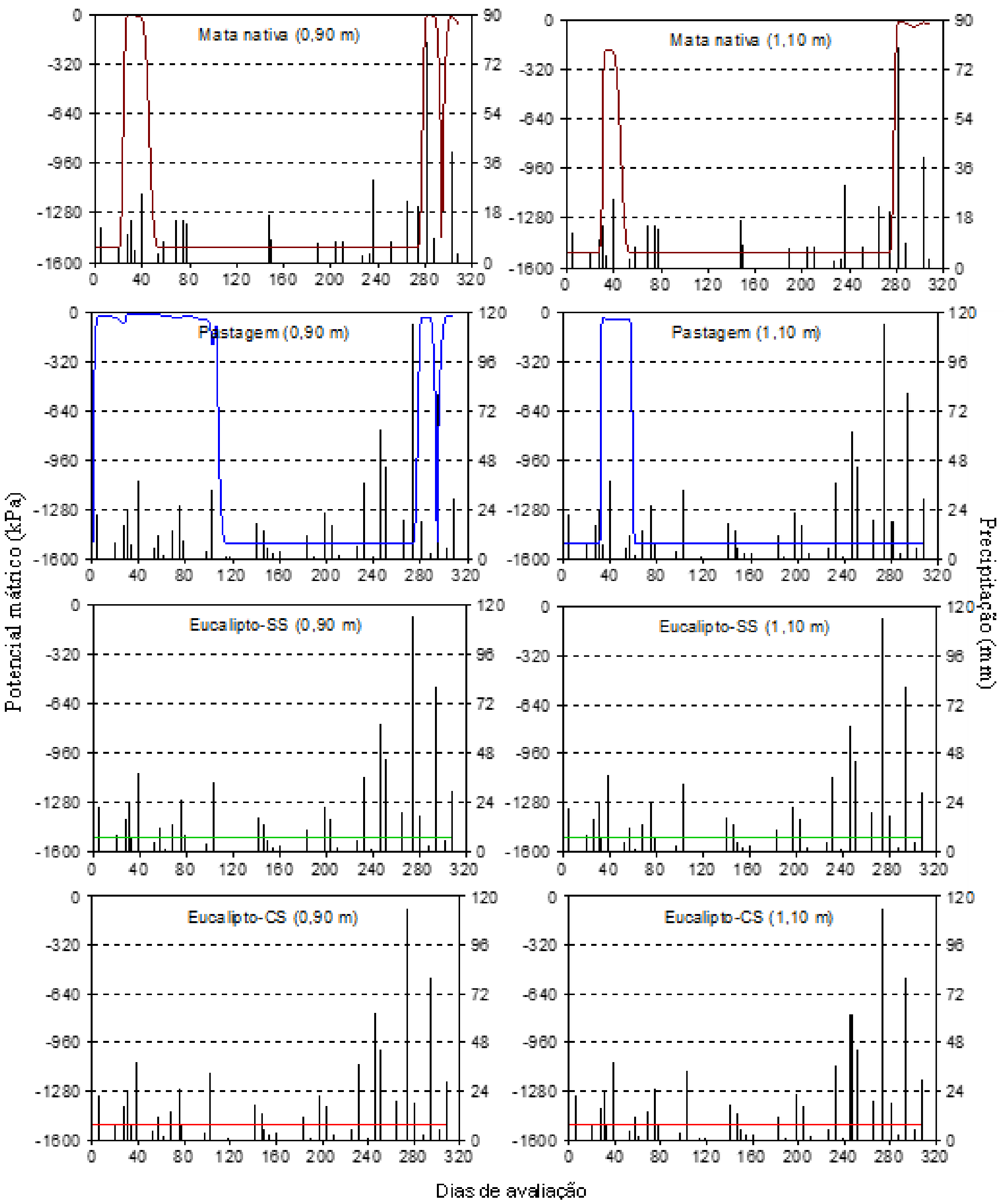


Throughout the evaluation period, the matric potential values at the lower soil limit evaluated remained constant in the eucalyptus environment (Figure 3), where this situation may be affected by the physical attributes of the soil. It was observed that micropores predominated over macropores throughout the soil profile, including in the Bw $_{1\ \mathrm{horizon}}$, where the lower soil limit evaluated was located (Table 2). According to Brady and Weil (2012), micropores are responsible for water retention in the soil; therefore, rainwater that infiltrates the profile remains retained by these capillary pores and does not percolate deeper into the profile.

The soil under pasture presented higher macropore values than micropores in the first horizons did (Table 2), facilitating water percolation through the profile in the first rainy season. However, from the Bt 1 horizon onwards, just below the cohesive layer, micropores prevailed, which hindered drainage, preventing water from reaching the lower limit (1.10 m), as shown in Figure 3.

The soil under native forest presented higher macropore values than micropores throughout the profile, starting at 0.21 m (Table 2), which allowed water percolation at depth, reaching matric potential values close to zero at the lower limit during the rainy season. However, the total potential gradient remained close to zero (Figure 2), and the matric potential was close to 1,500 kPa (Figure 3) for most of the evaluated periods.

Figure 3. Matric potential at the lower soil limits of the environments during the evaluation period in Cruz das Almas, Bahia



The interaction between environments and evaluation periods was significant, and its breakdown revealed that the native forest environment differed from the other environments in all periods, with the eucalyptus and pasture areas not differing from each other; on the other hand, there was a difference between the 2nd and 3rd periods in the pasture, which was not observed in the other environments (Table 4).

There was a difference in all the evaluation periods, with the 3rd period characterized as the driest period, which presented the lowest average evapotranspiration (64,5 mm), and the 4th period, which was characterized as the wettest, with the highest average (292,4 mm) (Table 4).

Table 4. Analysis of variance for environments (A) and evaluation times (E) and breakdown of the A × E interaction with their respective evapotranspiration means in Cruz das Almas, Bahia

Sources of variation	**G. L**	**Q. M**	**F**
Environments (A)	3	29,229.85	2225.17 **
Epochs (E)	3	127,916.47	42.45**
A x E Interaction	9	3148.68	26.26**
Residue	62	271.86	-
Total	71		
CV (%)	10.9		

Environments	Evaluation periods [1]				Averages
	1	2	3	4	
Pasture	-178.4 bA [2]	-131.8 bB	-70.7 BC	-325.1 bD	-176.5 b
Eucalyptus without subsoiling	-181.5 bA	-82.8 bB	-82.5 bB	-342.8 BC	-173.9 b
Eucalyptus with subsoiling	-182.6 bA	-82.4 bB	-80.7 bB	-348.8 BC	-170.9 b
Native forest	-80.6 aA	-38.3 aB	-24.1 aB	-157.6 BC	-75.2 a
Averages	-155.8 C	-83.8 B	-64.5 A	-292.4 D	-149.1
CV (%)	7.2				

(1) 1 = 07/29/16 to 10/28/16; 2 = 10/29/16 to 01/26/17; 3 = 01/27/17 to 03/23/17; and 4 = 03/24/17 to 05/31/17.
(2) Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ statistically from each other, according to the Tukey test (p<0.05).

The water balance data revealed that the highest ET values occurred during the period with the greatest water availability, and the lowest values occurred during the driest period (Figure 4). These results are similar to those obtained by Almeida *et al.* (2018), Souza *et al.* (2013) and Silva *et al.* (2014), who obtained higher ET values in periods with higher rainfall.

Much of the rainwater is retained in the treetops and does not reach the ground, which explains why the forest had lower precipitation values at all times (Figure 4).

Figure 4. Evapotranspiration and precipitation at the evaluation times in each environment studied in Cruz das Almas, Bahia

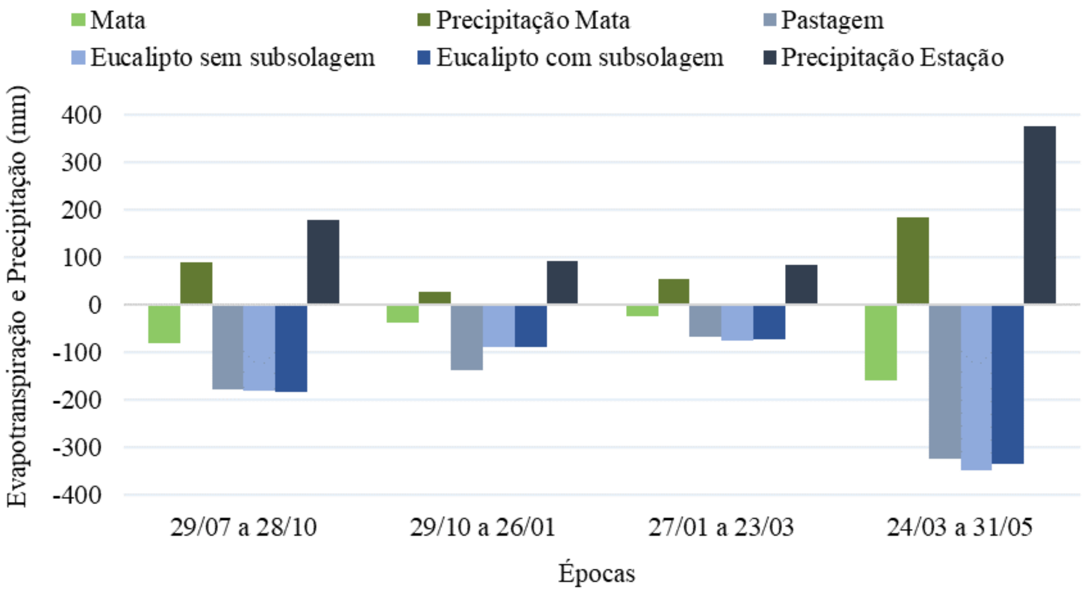
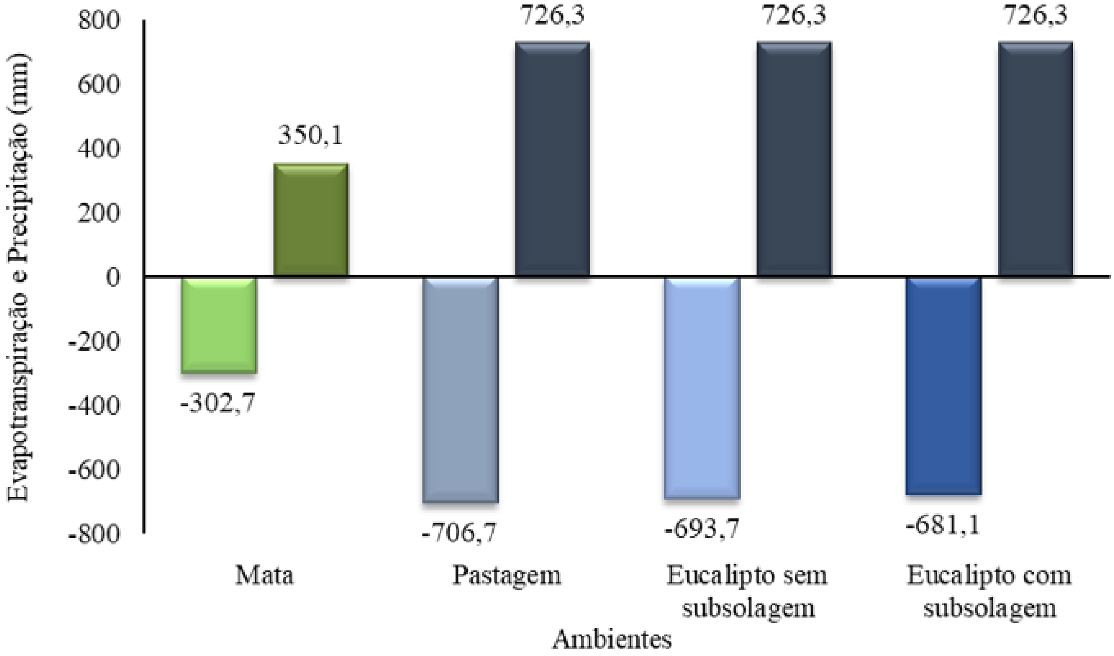


Figure 4 shows that, in the second evaluation period, there was a high ET in the pasture environment compared with the other environments, even though it was characterized as a dry season. This fact can be explained by the fact that the grasses cover the entire soil surface, which contributes to the water, resulting from the previous season (rainy), remaining stored in the soil profile longer and being gradually evapotranspired, which is accounted for in the following period.

This, therefore, influenced the high ET of the pasture, presenting, in fact, the highest value at that time, which was also reflected in a higher absolute value of ET in the total evaluation period (Figure 5).

Figure 5. Evapotranspiration and precipitation during the entire study period in the evaluated environments in Cruz das Almas, Bahia



The calculation of the ratio between millimeters of the evapotranspired layer per millimeter of the precipitated layer revealed the following values: 0,86 mmmm $^{-1}$ for forest; 0,97 mmmm $^{-1}$ for pasture; and 0.94 and 0,96 mmmm $^{-1}$ for eucalyptus in soil with and without subsoiling, respectively (Figure 5). Queiroz *et al*. (2017) reported values between 1.2 and 1.4 mmmm $^{-1}$ for eucalyptus, whereas Muniz *et al*. (2014), working with elephant grass, obtained values of 0,85 mmmm $^{-1}$, which are similar to those reported in this work.

Figure 5 shows that the water balance in the eucalyptus area subjected to subsoiling was lower than that in the area without subsoiling, although the difference was not statistically significant (Table 4). Most likely, in the plot where the subsoiler was not used, the water, after the rain, remained in the layer overlying the compacted layer, owing to the difficulty that this layer imposes on the redistribution of water in the soil profile; therefore, it is possible that, in this environment, there was a greater contribution of direct evaporation of water through the soil surface in the evapotranspiration process.

Evapotranspiration is known to be the sum of evaporation from the soil surface and plant transpiration. However, the former may contribute more than the latter does, and vice versa. In other words, transpiration may be more intense depending on the leaf area of the vegetation being studied, or evaporation may contribute to the transfer of water to the atmosphere in greater quantities, for example, if the soil under the crop being studied is not covered.

Notably, the soil under pasture is more sandy on the surface, above the cohesive layer, and presented lower total porosity and higher soil density (Table 2), meaning that there must have been a restriction on the redistribution of water in the profile, which accumulated in the most superficial horizons, thus presuming greater loss through evaporation.

Owing to the soil and water availability limitations of coastal landscape soils, the water regime in these soils is already quite limited due to their cohesive nature, which hinders water movement and, therefore, may have been reflected in the variation in soil water storage with the lack of rainfall during most of the study period.

7 CONCLUSIONS

1. Pastured and eucalyptus environments have higher evapotranspiration demands than native forests do, indicating that land use conversion has a direct effect on the water balance.
2. The cohesive horizon restricts the distribution of water in the profile and contributes to increased evapotranspiration of the soil layers above it.
3. The reduction in evapotranspiration coincides with the period of greatest water deficit in the soil.
4. In new research of this nature, it is advisable to quantify the direct evaporation of water through the soil surface to discriminate the individual contributions of evaporation and transpiration to the composition of evapotranspiration in different crop systems.

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9 REFERENCES

ALMEIDA, KSSA; SOUZA, LS; PAZ, VPS; COELHO FILHO, MA; HOCES, EH Soil water balance cultivated under a dense orchard of 'Pêra' orange grafted on different rootstocks. **Irriga** (UNESP. CD-ROM), Botucatu, v. 23, p. 235-248, 2018.

BRADY, NC; WEIL, R. **Elements of nature and soil properties** . 3rd ed. Porto Alegre: Bookman, 2012.

CINTRA, FLD; RESENDE, RS; LEAL, MDLS; PORTELA, JC Effect of irrigation water volumes on the water regime of cohesive soil of tablelands and on coconut production. **Brazilian Journal of Soil Science** , Viçosa, v. 33, n. 4, 2009.

CONSOLI, S.; LICCIARDELLO, F.; VANELLA, D.; PASOTTI, L.; VILLANI, G.; TOMEI, F. Testing the water balance model criteria using TDR measurements, micrometeorological data and satellite-based information. **Agricultural Water Management** , Amsterdam, v. 170, p. 68-80, 2016.

CORRÊA, MM; KER, JC; BARRON, V.; TORRENT, J.; CURI, N.; TORRES, TCP Physical, chemical, mineralogical and micromorphological characterization of cohesive and fragipan horizons of red and yellow soils of the Coastal Tablelands environment. **Brazilian Journal of Soil Science** , Viçosa, v. 32, p. 297-313, 2008.

DOURADO NETO, D.; NIELSEN, DR; HOPMANS, JW; REICHARDT, K.; BACCHI, OOS Computer program for modeling soil water retention curves (SWRC, version 2.00). **Scientia Agricola** , Piracicaba, v.57, p. 191-192, 2000.

GEE, GW; OR, D. Particle size analysis. In: DANE, JH; TOPP, GC (Ed). **Methods of soil analysis: Physical methods** . Madison: Soil Science Society of America, 2002. Chapter 16, p. 255-294. (SSSA Book Series, 5).

GROSSMAN, R.B.; REINSCH, TG Bulk density and linear extensibility. In: DANE, JH; TOPP, GC (Ed). **Methods of soil analysis: Physical methods** . Madison: Soil Science Society of America, 2002. Chapter 2, p. 201-228. (SSSA Book Series, 5).

LEDIEU, J.; RIDDER, P.; CLERCK, P.; DAUTREBANDE, S. A method for measuring soil water moisture by time domain reflectometry. **Journal of Hydrology** , Amsterdam, v.88, p.319-328, 1986.

LIBARDI, PL **Soil water dynamics** . 3rd ed. Piracicaba, 2018.

MARENGO, JA; CUNHA, AP; ALVES, LM The 2012-15 drought in the semiarid region of Northeast Brazil in historical context. **Climanalysis** , São José dos Campos, v. 3, p. 1-6, 2016.

MELO, IN; LEITE, ES; SOUZA, DR; NOBREGA, JCA; SANTOS, JS; DIAS, CN Spatial and temporal variability in the growth of *Eucalyptus grandis x Eucalyptus urophylla* under different soil preparations, fertilizations and genetic materials. In: Adriane Theodoro Santo Alfaro; Daiane Garabeli Trojan. (Org.). **Agronomy: Link in the Production Chain** . 2nd ed. Ponta Grossa- PR: Atena Editora, 2018, v. 2, p. 277-292.

MUNIZ, RA; SOUSA, EFD; MENDONÇA, JC; ESTEVES, BDS; LOUSADA, LDL Energy balance and evapotranspiration of Mombaça grass under rotational grazing system. **Brazilian Journal of Meteorology** , São José dos Campos, v. 29, p. 47-54, 2014.

NARANJO, ME; ATAROFF, M. Calibration of TDR equipment for use in undisturbed floors. **Interciencia** , Caracas, v. 40, n. 6, p. 416-422, 2015.

OLIVEIRA, LB Determination of macro and microporosity by tension table in soil samples with undeformed structure. **Brazilian Agricultural Research** , Rio de Janeiro, v. 39, p. 197-200, 1968.

QUEIROZ, TB; ROCHA, SMG; DA FONSECA, FSA; MARTINS, ER; ALVARENGA, ICA Effects of water deficit on the cultivation of Eucalyptus seedlings. **Irriga** , Botucatu, v. 22, p. 659-659, 2017.

RICHARDS, LA Methods of measuring soil moisture tension. **Soil Science** , Baltimore, vol. 68, p. 95-112, 1949.

SANTOS, HG DOS; JACOMINE, PKT; ANJOS, LHC DOS; OLIVEIRA, VA DE; LUMBRERAS, JF; COELHO, MR; ALMEIDA, JA; ARÚUJO FILHO, JC DE; OLIVEIRA, JB DE; CUNHA, TJF **Brazilian Soil Classification System** . 5th ed. Brasília, DF: Embrapa, 2018.

SAS INSTITUTE Inc. **SAS/STAT user's guide** . 4th ed. Raleigh: SAS Institute Inc., 2004. v. 9, 846 p.

SILVA, RAB; LIMA, JRS; ANTONINO, ACD; GONDIM, PSS; SOUZA, E. S; BARROS JÚNIOR, G. Water balance in Regolithic Neosol cultivated with brachiaria (*Brachiaria decumbens* Stapf). **Brazilian Journal of Soil Science** , Viçosa, v. 38, p. 147-157, 2014.

SILVA, AJP da; COELHO, EF; COELHO FILHO, MA Water extraction variability in the banana root zone affects the reliability of water balance. **Scientia Agricola** , Piracicaba, v. 72, n. 1, p. 1-10, 2015.

SILVEIRA, FGF; SOUZA, LS; PEREIRA, FAC; OLIVEIRA, AS; SILVA, FTS Water redistribution and field capacity in a dystrocohesive Yellow Latosol. **Magistra Magazine** , Cruz das Almas, v. 26, p. 221, 2014.

SOUZA, LS; SOUZA, LD; PAIVA, AQ; RODRIGUES, ACV; RIBEIRO, LS Distribution of citrus root systems in a soil toposequence of the Coastal Tableland of Bahia State. **Brazilian Journal of Soil Science** , Viçosa, v. 32, n. 2, 2008.

SOUZA, C.; ANDRADE, AP; LIMA, JRS; ANTONINO, ACD; SOUZA, ES; SILVA, IF Water balance of castor bean crop under rainfed conditions. **Brazilian Journal of Agricultural and Environmental Engineering** , Campina Grande, v. 17, p. 3-10, 2013.

TAXONOMY, S. Soil survey staff. **Keys to Soil Taxonomy** . USDA, Ninth Edition, 332p, 2003.

UMENYIORA, CA; DRUCE, RL; CURRY, R.D.; NORGARD, P.; MCKEE, T.; BOWDERS, JJ; BRYAN, DA Dielectric constant of sand using TDR and FDR measurements and prediction models. **IEEE Transactions on Plasma Science** , New York, v. 40, n. 10, p. 2408-2415, 2012.